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Long-term Outcomes After Total Ankle Arthroplasty: A Systematic Review

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Abstract

Background: Total ankle arthroplasty has emerged as a treatment to successfully treat ankle arthritis. Recent studies have reported more than 40 000 total ankle arthroplasties (TAAs) being performed between 2009 and 2019 in the United States. Although recent studies have reported favorable patient-reported outcomes at short- and midterm follow-up, there is a paucity of aggregate literature reporting on long-term patient-reported outcomes (PROs) after TAA. The purpose of this review is to report an aggregate of literature on minimum 10-year patient-reported outcomes after TAA.
Methods: A systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. PubMed, Scopus, and Cochrane Central Register of Controlled Trials (CENTRAL) were queried in June 2024. Primary research articles were included if they reported minimum 10-year PROs or satisfaction for patients who underwent primary TAA and were written in English. Survivorship was reported based on implant failure, which was determined uniquely by each study.
Results: Eight studies met the inclusion criteria. A total of 595 ankles with a range of average ages from 51 to 73.7 years were included in the study with follow-up ranging from a minimum of 10 years to a minimum of 20 years. Six of the 8 studies reported average follow-up ranging from 11.9 to 15.8 years. Two of the 8 studies reported significant improvement in PROs following surgery. Survivorship at a minimum of 10-year follow-up ranged from 66% to 94.4%. Average time to implant failure ranged from 4.6 to 13.8 years.
Conclusion: Patients undergoing primary TAA were reported to have generally improved PROs at minimum 10- year follow-up. However, they demonstrated variable rates of survivorship ranging from 66% to 94.4%. Of those experiencing implant failure, average time to failure ranged from 4.6 to 13.8 years. Survivorship should be interpreted with caution because of varying definitions between studies. Further studies should seek to standardize the definition of survivorship and reporting of PROs to allow for effective analysis of heterogeneity.

Keywords: arthritis, arthroplasty, patient-reported outcomes, survivorship, total ankle arthroplasty

Introduction

Ankle arthritis is a debilitating condition that was previously solely surgically treated with ankle arthrodesis.[25] However, total ankle arthroplasty (TAA) has emerged as an alternative that leads to a greater range of motion after surgery while providing similar outcomes when compared to ankle arthrodesis.[7,26,27] Recent trends have shown that the use of TAA has increased whereas the use of ankle fusion has decreased in the United States.[24] TAA's growing popularity is evident with more than 40 000 TAAs performed in the United States from 2009 to 2019.[15]

As a result, there has been an increasing amount of literature reporting on patient-reported outcomes (PROs) after TAA and implant survival rates.[8,10,20] A review of the literature including more than 1000 ankles with minimum 5-year follow-up demonstrated that TAA has favorable outcomes.[22] This review found the mean difference between preoperative and postoperative American Orthopaedic Foot & Ankle Society (AOFAS) ankle-hindfoot score was 43.60. It also concluded

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that pooled prosthesis revision rates, excluding polyethylene exchanges, were 12.2% at minimum 5-year follow-up and 20.2% at minimum 10-year follow-up.[22] However, minimum 10-year data is scarce and further reviews are necessary to determine whether there is durability between midterm and long-term outcomes after TAA. The purpose of this review is to report an aggregate of literature on minimum 10-year patient-reported outcomes after TAA. The authors hypothesize that patients who did not undergo revision surgery would experience favorable outcomes and that there would be a moderate rate (20%) of implant failures at long-term follow-up.

Methods

Study Selection

A systematic review was conducted in PubMed, Scopus, and Cochrane Central Register of Controlled Trials (CENTRAL) in June 2024 following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. A medical librarian was consulted in developing the search terms and extracted articles from the three databases. The search strategy is detailed in Appendix Table 1. The review was registered in Prospero under id: CRD42023393629. Articles were included if they were primary research articles reporting PROs or satisfaction after primary TAA with minimum 10-year follow-up in English. Articles were excluded if they were animal studies, biomechanical studies, case reports, opinion articles, review articles, technique articles, or did not report postoperative outcomes. Articles underwent title and abstract screening and full-text review by 2 independent reviewers (M.S.L.) and (L.M.). Disagreements were settled by rereview and discussion until reviewers were in unanimous agreement.

Quality Assessment

All studies were graded for quality using the Methodological Index of Non-Randomized Studies (MINORS).[28] Two independent reviewers (M.S.L.) and (L.M.) assessed each article, and disagreements were settled by regrading and discussing the scoring criteria until reviewers were in agreement. Articles that did not report level of evidence were assigned levels of evidence based on the standards previously described by Hohmann et al.[12]

Data Extraction and Analysis

Patient-reported outcomes and endpoint and nonendpoint surgery rates were extracted. Additionally, patient demographics, functional outcomes, radiographic findings, and surgical procedures were extracted, if available. Average time to implant failure was calculated by summing up time to endpoint revision surgeries for all patients and dividing by the number of people who had implant failure if studies did not explicitly report average time to implant failure. Average time to specific non-endpoint secondary procedures were calculated using the same method. Forest plots were created for PROs with preoperative and postoperative values for 3 or more studies using Cochrane's Review Manager program (RevMan Version 5.4; The Nordic Cochrane Center, The Cochrane Collaboration, 2020). The latest postoperative outcome was used when multiple time points were reported over 10-year follow-up. Heterogeneity was assessed with I^2 using the Cochrane Handbook cutoffs. The I^2 range of 50%-90% "may represent substantial heterogeneity."[11] Data were not pooled because of low levels of evidence.[5] Statistical significance was defined as $P < .05$. Survivorship was defined as nonimplant failure and assessed for each cohort using the definitions provided in their respective studies. Time to implant failure and follow-up time were converted to years by dividing the number of months by 12.

Results

The initial query on PubMed, CENTRAL, and Scopus resulted in 3633 articles. There were 2470 articles remaining after duplicates were removed. Title and abstract review of the remaining articles for relevance yielded 42 articles for full-text review. The full text of these articles was reviewed, and 8 of these articles met inclusion criteria and were included in the study.[1-4,6,14,18,23] The article selection process is shown in Figure 1. Seven of the studies included in the systematic review were case series representing Level IV evidence.[2-4,6,14,18,23] One study was a retrospective cohort study representing Level III evidence.[1]

Demographics

Descriptive article information including study period, number of ankles, sex, average follow-up time, and average age at time of surgery were recorded (Table 1). The 8 studies in this review had study periods ranging from 1984[1] to 2009.[2] This review included a total of 595 ankles, of which 235 ankles had PRO follow-up of at least 10 years. Average age of patients ranged from 51 years[1] to 73.7 years[23] with follow-up ranging from a minimum of 10 years to a minimum of 20 years. Six out of 8 studies reported average follow-up ranging from 11.9 to 15.8 years.

Range of Motion and PROs

Three of the studies recorded pre- and postoperative ankle range of motion (ROM).[2,6,14] These 3 studies all found improvement in dorsiflexion from pre- to postoperative measurements, and one of the studies found a significant improvement in total ROM following surgery.[2] Two studies[3,23] reported only postoperative ankle ROM. Six of the 8 studies reported radiographic measurements including alpha, beta, and gamma

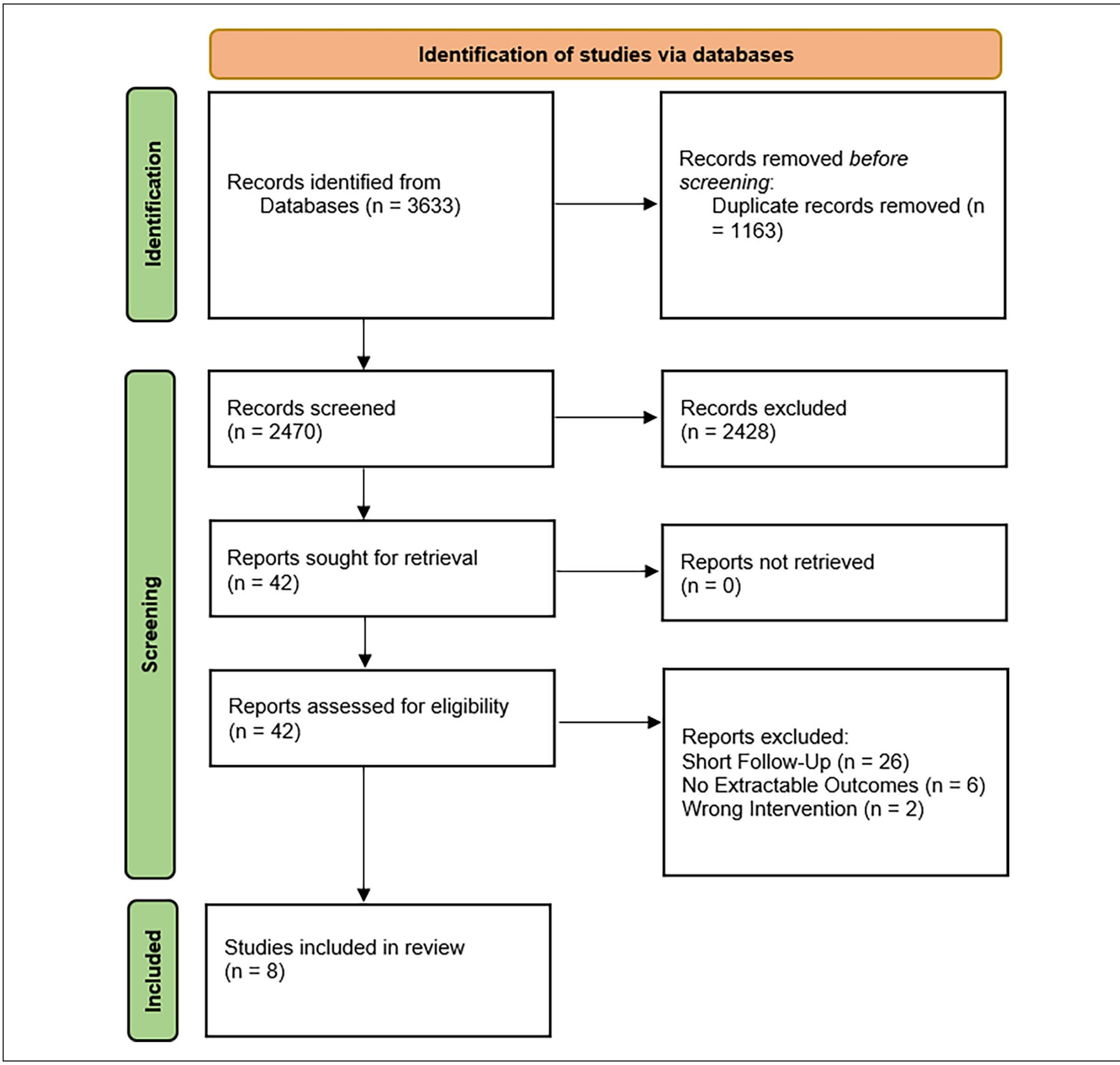

Figure 1. Prisma Flowchart for Article Selection.

angles.[1-3,6,14,23] Radiographic measurements and ankle range of motion results were recorded (Appendix Table 2).

All 8 studies reported PROs, with the most common PRO reported being the AOFAS ankle-hindfoot scale, which was utilized in 6 studies.[2-4,14,18,23] The average preoperative AOFAS score ranged from 25 points[3] to 39.6 points[23] of 100. The average postoperative AOFAS score ranged from 61 points[4] to 80.4 points[18] of 100. Of the 6 studies that recorded AOFAS scores, 2 of the studies[2,3] reported statistically significant improvements after surgery. The remaining 4 studies[4,14,18,23] demonstrated improvements in AOFAS scores postoperatively but without statistical significance. Improvement was calculated as the difference between average postoperative and average preoperative outcome scores. The difference between preoperative and postoperative scores ranged from 32 to 53.9. Additionally, PRO for pain was recorded using the visual analog scale (VAS) in 3 of the studies.[2,3,14] Only 2 of these studies[2,14] recorded both pre- and postoperative VAS scores, with 1 of the studies demonstrating significant improvement.[2] Exploring heterogeneity for AOFAS score yielded an I^2 of 67%, which indicates there could be substantial heterogeneity between the studies reporting AOFAS scores. Additional PRO measures used included the Foot Function Index (FFI),[2] which demonstrated significant improvement following surgery. PROs are

Table 1. Demographics.

Author and Year	Model	LOE	Study Type	Study Period	MINORS	Ankles (n)	Sex (n)	Follow-up,[a] y	Age,[a] y
Bianchi et al[2] 2021	Bologna-Oxford (BOX)	IV	Case series	2004-2009	13	52 in study (34 PROs)	17 M 17 F	11.9 ± 1.4 (10.1-14.4)	54 ± 12.1 (26-74)
Brunner et al[3] 2013	STAR	IV	Case series	1996-2000	15	62 in study (33 PROs)	35 M 37 W	12.4 ± 1.26 (10.8-14.9)	56.9 ± 13.9 (22.3-84.5)
Clough et al[4] 2019	STAR	IV	Case series	1993-2000	13	87 in study (49 PROs)	39 M 45 W	15.8 (11.1-24.5)	54 (18-72)
Frigg et al[6] 2017	STAR	IV	Case series	1996-2006	14	50 in study (28 postoperative PROs)	20 M 26 F	<u>14.6</u>{12.9-16.4}	<u>58.0</u> [38.0-81.8]
Jastifer and Coughlin[14] 2015	STAR	IV	Case series	1998-2003	10	41 in study (18 PROs)	10 M 8 F	12.6 (10.2-14.6)	60.9 (44-73)
Kraal et al[18] 2013	First 19 LCS mobile-bearing TAR (DePuy), 74 with Buechel-Pappas mobile-bearing TAR (Endotec)	IV	Case series	1988-1999	15	93 in study (17 postoperative PROs)	NR	14.8 (10.7-22.8)	57.6 (26.7-81.0)
Palanca et al[23] 2018	STAR	IV	Case series	1998-2000	13	84 in study (24 with PROs)	NR	15.7 (15.0-17.7)	73.7 (51.3-92.9)
Bedard et al[1] 2021	Agility	III	Retrospective cohort study	1984-1994	13	126 (32 with follow-up)	NR	Minimum 20	51 (37-77)

Abbreviations: F, female; LCS, low contact stress; LOE, level of evidence; M, male; NR, not reported; PRO, patient-reported outcome score; STAR, Scandinavian Total Ankle Replacement; TAR, total ankle replacement.
[a]Data are reported as mean ± SD (range) or {95% CI} and median [interquartile range]; underline denotes median.

Table 2. Patient-Reported Outcomes and Clinical Benefit.[a]

Author and Year	Ankles (n) With PROs	PROs	Preoperative	Postoperative	*P* Value	Improvement
Bianchi et al[2] 2021	34	VAS for pain	8.5 ± 1.2	2.9 ± 2.2	<.01	NR
		AOFAS	28.6 ± 11.9	72.7 ± 16.9	<.01	
		FFI-pain	76.2 ± 14.2	31.4 ± 25.6	<.01	
		FFI-disability	77.6 ± 19.3	26.7 ± 25.4	<.01	
		Satisfaction		Would undergo surgery procedure if under the same conditions (33/34, 97%) Dissatisfied (1/34)		
Brunner et al[3] 2013	33	VAS for pain		2.4 ± 2.3 (0 to 9)	NR	NR
		AOFAS	25 ± 10 (3 to 44)	73 ± 17 (17 to 97)	≤.05	NR
		Modified Coughlin Satisfaction Scale		Satisfied or very satisfied (27 ankles, 82%) Moderately satisfied (3 ankles, 15%) Dissatisfied (1 ankle, 3%)	NR	NR
		Satisfaction		Would undergo surgery again (all patients but 2)		
Clough et al[4] 2019	49	AOFAS	28 (10 to 52)	61 (20 to 99)	NR	NR
Frigg et al[6] 2017	50 preoperative, 28 postoperative	Kofoed	<u>48.5</u> [42.5 to 56]	<u>89</u> [81 to 94]	NR	38.0 (−15 to 66)
Jastifer and Coughlin[14] 2015	18	VAS for pain	8.1 (6 to 10)	2.1 (0 to 8)	NR	NR
		Buechel-Pappas	42.8 (39 to 48)	82.1 (45 to 96)		
		AOFAS	32.8 (21 to 42)	78.1 (41 to 100)		
		Coughlin Satisfaction Scale		Excellent (14/18) Good (4/18)		
		Functional VAS walking				
		Flat surface		0.3 (0 to 4)		
		Upstairs		1.3 (0 to 5)		
		Downstairs		1.4 (0 to 5)		
		Uphill		0.7 (0 to 3)		
		Downhill		0.9 (0 to 4)		
		Uneven surface		2.7 (0 to 10)		
Kraal et al[18] 2013	93 preoperative, 17 postoperative	AOFAS	26.5 {24.1 to 28.8}	80.4 {72.4 to 88.4}	NR	NR
Palanca et al[23] 2018	24	AOFAS	39.6	71.6 points (range 42 to 89)	NR	NR
Bedard et al[1] 2021	32	Satisfaction		Satisfied (32 ankles) No ankle pain (8 ankles) Occasional ankle pain (21 ankles) Daily ankle pain (3 ankles) Increase in function (29 ankles)	NR	NR

Abbreviations: AOFAS, American Orthopaedic Foot & Ankle Society; AOS, Ankle Osteoarthritis Scale; FFI, Foot Function Index; NR, not reported; PROs, patient-reported outcome scores; VAS, visual analog scale.

[a]Data are reported as median or average ± SD (range) or {95% CI} or [interquartile range]; underline denotes median.

Study or Subgroup	Postop Outcome Mean	SD	Total	Preop Outcome Mean	SD	Total	Std. mean difference IV, Random, 95% CI
Bianchi et al.	72.7	16.9	34	28.6	11.9	34	2.98 [2.28 , 3.68]
Brunner et al.	73	17	33	25	10	33	3.40 [2.63 , 4.17]
Kraal et al.	80.4	16.8	17	26.5	11.6	93	4.28 [3.51 , 5.05]

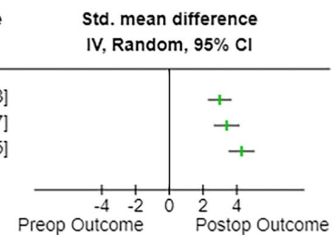

Figure 2. Forest Plot for American Orthopaedic Foot & Ankle Society (AOFAS) preoperative and postoperative scores.

recorded in Table 2. Forest plot showing the pre- and postoperative AOFAS is shown in Figure 2.

Revision surgeries and survivorship. Endpoint surgeries and reasons for endpoint revision (Table 3) and survivorship (Table 4) were recorded. The average time to implant failure of the studies ranged from 4.6 years[1] to 13.8 years.[14] Implant failures were most commonly treated with component revision or ankle arthrodesis. Aseptic loosening was the most common reason for implant failure in 3 studies[2,4,18] and tied for the most common reason in 2 other studies.[6,23] The average survivorship at a minimum of 10 years ranged from 66%[1] to 94.4%.[14]

Five studies reported conducting polyethylene exchanges.[1,3,6,14,23] One study reported that 17 ankles (22%) underwent open arthrolysis and percutaneous lengthening of the Achilles tendon.[3] Non-endpoint secondary surgeries are listed in Appendix Table 3.

Discussion

The main findings of this review were that (1) patients undergoing TAA with minimum 10-year follow-up showed improved patient-reported outcomes and (2) there are several definitions of survivorship, with studies reporting rates between 66% and 94.4%. Overall, there were a total of 595 ankles, of which 235 ankles had PRO follow-up of at least 10 years.

All 8 studies reported improvement between preoperative and postoperative outcomes after TAA. Improvement in AOFAS scores at long-term follow-up are consistent with the mean improvement after TAA at midterm follow-up of 43.6 (95% CI, 37.51-49.69) reported by Onggo et al.[22] This may show that outcomes from midterm to long-term follow-up after TAA are durable with minimal degradation over time. However, many studies may have omitted PRO data because of endpoint surgeries which could have influenced outcomes. One study reported Kofoed scores with a median improvement of 38 points after surgery and median postoperative score of 89 (interquartile range, 81-94).[6] Previous studies have defined that 89 would be an excellent outcome and the lower bound of the interquartile range of 81 would be a good outcome.[16] These results show that there may be sustained improvement in long-term outcomes after TAA.

It is important to note the high level of heterogeneity in the AOFAS scores. Heterogeneity measures the consistency between preoperative and postoperative AOFAS scores across studies and quantifies how much of the differences between the studies may be due to random chance. It can help determine if one study's results significantly vary from the expected results. There was an I^2 value of 67%, which indicates there could be "substantial heterogeneity."[11] This may be due to the small sample size of included studies with varying standardized mean difference effect sizes ranging from 2.98 to 4.28. The 4.28 effective size of the Kraal et al[18] study may have increased the heterogeneity due to 93 ankles having preoperative PROs and 17 ankles having postoperative PROs. Although the risk of heterogeneity influencing the current results is high, it is important to note that all 3 studies demonstrated positive standardized mean differences in favor of TAA.[2,3,18] This scarcity of studies undergoing I^2 analysis are a limitation of the current literature and should not invalidate the improvement TAA can offer patients with arthritis. Future studies should report standardized PROs at preoperative and minimum 10-year follow-up with SD to allow for qualitative analysis of the heterogeneity of the data to validate the findings of the current review.

The survivorship rates of the study should be evaluated with caution as there were multiple definitions of what constituted survivorship. The highest rate of 10-year survival by Jastifer and Coughlin[14] was 94.4% and defined by retaining the original implant. However, it is important to note that 6 of the 18 patients in that study had secondary surgeries to maintain the original implant that were not defined as failure. Five of these patients had polyethylene exchanges. The high rate of implant survival may be due to the exclusion of polyethylene exchanges as 2 other studies that reported survivorship rates of 82.8%[4] and 78%,[6] respectively, included polyethylene exchanges in their survivorship rates. When excluding polyethylene exchanges and cyst fillings, the 10-year survival rate increased from 78% to 90%.[6] The lowest rate of survivorship was reported at 66% and defined as a revision to the tibial, talar, or both components or a conversion to arthrodesis.[2] Furthermore,

Table 3. Deaths, Average Time to Implant Failure, Endpoint Revision Procedures, and Reasons for Revision.[a]

Author and Year	Deaths, n (%)	Implant Failure, n (%)	Time to Failure, y, Mean ± SD	Reasons for Revision, n (%)		Endpoint Revision Procedure, n (%)	
Bianchi et al[2] 2021	7 patients (8.7)	20 (37)	4.6 ± 3.5	Aseptic loosening	14 (70)	Ankle arthrodesis	11 (55)
				Severe residual pain	4 (20)	Revision TAA	9 (45)
				Infection	1 (5)		
				Talar necrosis	1 (5)		
Brunner et al[3] 2013	12 patients (13 ankles)	29	7.4 (1.8-13.4)	Aseptic loosening of talar component	4	Revision of talar component	3
				Aseptic loosening of tibial component	2		
				Aseptic loosening of both components	3	Revision of talar and tibial component	25
				Subsidence of talar component	11	Ankle arthrodesis	1
				Cyst formation on tibial and talar side	5		
				Recurrent inlay fracture	1		
				Varus instability	1		
				Valgus instability	1		
				Periprosthetic infection	1		
Clough et al[4] 2019	113 ankles, 100 patients	32	6.8 (0.2-21.4)	Aseptic Loosening	19 (59)	Ankle arthrodesis	14
				Edge loading of the implants from coronal plane malalignment causing edge loading of the polyethylene bearing	8 (25)	Tibiotalocalcaneal fusion	8 (25)
				Polyethylene component excessive wear	3 (9)	Polyethylene component exchange	4
				Stress fracture	1	Revision TAA	6
				Delayed wound healing	1		
Frigg et al[6] 2017	4 patients	18		Aseptic loosening	12	Ankle arthrodesis	4
						Revision of tibial component	4
						Revision of talar component	1
				Cysts	12	Filling of cysts	12
				Broken polyethylene	3	Replace broken polyethylene	3
Jastifer and Coughlin[14] 2015	8	1	13.8			Explant and tibiotalocalcaneal arthrodesis	1
Kraal et al[18] 2013	30 patients, 39 ankles	23	8.3	Aseptic loosening	9 (39)	Arthrodesis	17 (18.3)
				Infection	3 (13)	Talar component + bearing exchange	1
				Deformity	8 (35)		
				Osteolysis	2 (9)	Exchange of all components	1
				Broken insert	1 (4)	Insert exchange + graft talar cyst	2
						2-stage revision	1
						Insert exchange	1
Palanca et al[23] 2018	5	14	7.6[b]	Aseptic loosening	4	Fusion	7
				Osteolysis with implant instability	2	Revision	4
				Implant subsidence	3	Unknown	4
				Unstable talar component	1		
				Talar AVN	1		
				Unknown	4		
Bedard et al[1] 2021	87 patients (69) 93 ankles (70.5)	19 (15)	NR	NR		Polyethylene liner exchange	5
						Revision of both components	4
						Revision of talar component	1
						Amputations[c]	2

Abbreviation: TAA, total ankle arthroplasty.
[a]Data are reported as n (%) or mean ± SD (range) unless otherwise indicated.
[b]Four patients had revision surgeries at unknown times and were not factored into average time to implant failure.
[c]Unrelated to ankle arthroplasty.

Table 4. Definitions of Survivorship (Nonimplant Failure) and Survivorship Rates.

Paper Author	Survivorship Definition	Survivorship (%) at 10y
Bianchi et al[2]	No revision of either the tibial or talar metallic component or conversion to arthrodesis	66
Brunner et al[3]	No revision or removal of the talar and or tibial metallic components or conversion to ankle fusion	70.7
Clough et al[4]	No revision of 1 or all of the components including polyethylene exchange or conversion to arthrodesis	82.8
Frigg et al[6]	Definition 1: No replacement of the whole prosthesis or conversion to arthrodesis or amputation	94
	Definition 2: Definition 1 and no exchange of at least one metallic component	90
	Definition 3: Definition 2 and no exchange of inlay due to breakage or wear	78
Jastifer and Coughlin[14]	No failure of either the tibial or the talar metallic component	94.4
Kraal et al[18] 2013	No exchange of 1 or more components of arthrodesis	81
Palanca et al[23]	No complete explant including either conversion to an arthrodesis or revision of metal prosthetic components	90
Bedard et al[1] 2021	Definition 1[a]: Avoiding reoperation (component loosening, arthrodesis, liner exchange, bone grafting, screw removal, or amputation)	75
	Definition 2[a]: tibial component free of revision for aseptic failure	87.4
	Definition 3[a]: talar component free of revision for aseptic failure	86.5

[a]At minimum 20 years.

this cohort had an extremely high satisfaction rate despite the high amount of failures as only 1 of the 34 patients was dissatisfied.[2] The survivorship rate here is lower than previous rates of 97%[21] reported at midterm follow-up and could possibly be due to the high loss of follow-up as 28 patients were deceased (8.7%) or were unable to be contacted (26.2%).[2] The variable definitions of what constituted implant survival should be considered when evaluating literature concerning the survivorship rates after TAA.

Further original research studies and systematic reviews should seek to standardize the definition of survivorship and implant failure to allow for more in-depth analyses. A universal definition of what constitutes survival could eventually lead to pooled data for systematic reviews. This would allow for accurate estimations of the likelihood of avoiding revision surgery after TAA and estimated average time to implant failure. Moreover, future reviews should seek to evaluate the long-term efficacy of TAA in comparison to arthrodesis. Multiple reviews have compared the 2 techniques at shorter follow-up; however, it is necessary to understand the long-term outcomes of both procedures.[9,17] Further reviews should evaluate higher-quality evidence with randomization as all studies in the current review were case series with Level IV evidence or retrospective cohort studies with Level III evidence, which prevented data from being pooled.

This article has several strengths. First, the review evaluates patients with minimum 10-year outcomes, which can help assess the durability of outcomes after TAA. These results can build on previous reviews and help orthopaedic surgeons manage patient expectations on the longevity of their TAA. Second, the review uses forest plots to evaluate whether heterogeneity may influence PROs after TAA. This can help determine whether differences from studies may be due to random chance or the methodology and results of a specific study. In the current review, the high heterogeneity led to further analysis of effect sizes and found that lack of postoperative scores may have led to the high effect size. Third, the review provides a comprehensive list of secondary procedures after TAA. This list provides context on possible complications and further procedures patients may experience after TAA excluding secondary TAA or arthrodesis.

This study has limitations that must be acknowledged. All included studies were case series, which introduces considerable heterogeneity and bias into the study. Many patients had additional interventions, before, during, or after the implantation of the prosthesis, which may confound outcomes. Moreover, surgical technique has evolved over the years, and the outcomes of this review may not reflect the efficacy of modern total ankle arthroplasty. Certain implants included in the study may not be used currently. During the study period, the most commonly recorded assessments of the patients were the AOFAS scores. The AOFAS scoring systems are not purely patient-reported as they have aspects of the score completed by the surgeon. Although they have been previously defined as a PRO by multiple studies[13,19] and used in ankle osteoarthritis, their utility is suspect and is not equivalent to validated scoring systems. Additionally, the forest plot has a high heterogeneity of $I^2 = 95\%$, which must have influenced the outcomes of the study. Also, no pooling of outcomes was performed because of low levels of evidence. Moreover, no subanalysis comparing TAA to arthrodesis was performed because of the novelty of 10-year follow-up and lack of comparative studies in the literature. The sample size of the review is modest, and further studies are needed to validate the results. Readers should cautiously interpret survivorship rates because survivorship definitions varied between studies. Finally, some patients were considered endpoints because of revision surgery or death and were not included in the postoperative patient-reported outcomes, which may have influenced the reported outcomes.

Conclusion

Patients undergoing primary TAA were reported to have generally improved outcomes at minimum 10-year follow-up. However, they demonstrated variable rates of survivorship ranging from 66% to 94.4%. Of those experiencing implant failure, average time to failure ranged from 4.6 to 13.8 years. Survivorship should be interpreted with caution because of the varying definitions between studies. Further studies should seek to standardize the definition of survivorship and reporting of PROs to allow for effective analysis of heterogeneity.

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Ethical Approval

This study was performed in accordance with the ethical standards in the 1964 Declaration of Helsinki.

Declaration of Conflicting Interests

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Appendix Table 1. Search Strings for Databases.

Database	Search
PubMed	(("Arthroplasty, Replacement, Ankle"[Mesh]) OR ("Ankle"[Mesh] AND "Arthroplasty, Replacement"[Mesh])) OR ((ankle*[Text Word]) AND (replacement[Text Word] OR arthroplasty[Text Word]))) AND ((((("Patient Outcome Assessment"[Mesh]) OR "Treatment Outcome"[Mesh]) OR "Prosthesis Failure"[Mesh]) OR "Second-Look Surgery"[Mesh]) OR (((((outcome measure*[Text Word]) OR (outcome assessment*[Text Word])) OR (treatment outcome*[Text Word])) OR (failure[Text Word])) OR (reoperation[Text Word])))
Cochrane Center of Registered Trials	#1 ankle* NEAR/3 (replacement* OR arthroplasty) 102 #2 outcome measure* OR outcome assessment* OR treatment outcome* OR failure OR reoperation 728565 #3 #1 AND #2 in Trials 65
Scopus	(TITLE-ABS-KEY (ankle* W/3 (replacement* OR arthroplasty)) AND TITLE-ABS-KEY ("outcome measure*" OR "outcome assessment*" OR "treatment outcome*" OR failure OR reoperation))

Appendix Table 2. Radiographic Measurements, Range of Motion, Intraoperative Findings, and Surgical Procedures.

Author and Year	Radiographic Measurements and Findings	Range of Motion, degrees			Intraoperative Findings	Surgical Procedures
Bianchi et al[2] 2021	Heterotopic ossification: 31/34 TAAs demonstrated III-IV grade	Dorsiflexion in degrees	Preop: 3.5 (0 to 10)	Postop: 4.7 ± 6.8	NR	Additional procedures: subtalar arthrodesis for subtalar osteoarthritis (7) double arthrodesis (subtalar and talonavicular arthrodesis) for hindfoot osteoarthritis (2) medializing calcaneal osteotomies for hindfoot valgus (2)
	Initial post op: average value angles (degrees) 93.01 (α) 89.8 (β) 23.02 (γ)	Plantarflexion in degrees	Preop: 13.97 (0 to 30)	Postop: 15 ± 8.0		hardware removals (3) Achilles tendon lengthening (7) lengthening of the gastrocnemius fascia (2)
	Last follow-up: average angle values ($P > .05$) no significant difference from initial 93.7 (α) 89.02 (β) 21.93 (γ)	Total ROM:	Preop: N/A	Postop: total ROM of 19 ($P > .05$)		malleolar osteosynthesis for iatrogenic intraoperative fracture (2)
Brunner et al[3] 2013	Heterotopic ossification: 30/33	Tibiotalar in degrees (dorsoplantar)	Preop: NR	Postop: 23.6 ± 7.2 (17 to 39)	NR	NR
	Final follow-up: average angle values 89.6 ± 3.1 (79.6 to 94.7) (α) 89.6 ± 4.0 (82.2 to 100.0) (β) 18.5 ± 2.9 (13.8 to 24.0) (γ)	Subtalar in degrees (invert/evert)	Preop: NR	Postop: 22.7 ± 12.9 (0 to 45)		
Clough et al[4] 2019	NR	NR			NR	NR
Frigg et al[6] 2017	Preop TAS angle: 90 (86 to 92)	Postop TAS: 89 (88 to 92)	Preop dorsiflexion: 0 (−5 to 5)	Postop dorsiflexion: 5 (0 to 5)	NR	NR
	Preop TLS angle: 82 (78 to 86)	Postop TLS: 89 (84 to 92)	Preop plantarflexion: 30 (20 to 30)	Postop plantarflexion: 28 (20 to 30)		
	Preop TTA: n/a	Postop TTA: 0				

(continued)

Appendix Table 2. (continued)

Author and Year	Radiographic Measurements and Findings	Range of Motion, degrees			Intraoperative Findings	Surgical Procedures
Jastifer and Coughlin[14] 2015	The mean preop coronal deformity was 1.7 degrees of varus (range, 17 degrees of valgus to 12 degrees of varus); 15 of 18 patients had some degree of deformity, 9 had congruent deformity and 6 had incongruent deformity. Of those with a valgus deformity, the mean deformity was 6.2 degrees. Of those with a varus deformity, the mean deformity was 7.6 degrees. The mean postoperative tibial baseplate alignment was 2.1 degrees of varus and 4.7 degrees of dorsiflexion relative to the tibial axis. The talar component was nearly neutral (0.2 mm anterior) and slightly plantarflexed (2 degrees) at final follow-up.	Dorsiflexion in degrees Plantarflexion in degrees	Preop: 0.2 (−15 to 20) Preop: 23.6 (10 to 45)	Postop: 4.9 (−10 to 15) Postop: 22.2 (8 to 40)	NR	Single surgeon Concomitant procedures: lateral ligament reconstruction with an autograft (2) Dwyer calcaneal osteotomy and gastrocnemius recession (1) ORIF of an intraoperative posterior malleolus fracture (1) ORIF distal fibula fracture (1)
Kraal et al[18] 2013	NR	NR			NR	NR
Palanca et al[23] 2018	Heterotopic ossification: 13 (61.9%)	Dorsiflexion Plantarflexion Total ROM	Preop: NR Preop: NR Preop: NR	Postop: 2.5 (−10 to 15) Postop: 14.3 (−7 to 30) Postop: 17 (5 to 30)		NR
Bedard et al[1] 2021	Migration of tibial component: 1 (8.3%) Subsidence of tibial component: 2 (16.7%) Tibial osteolysis: 2 (16.7%) Incomplete radiolucent lines: 7 (58%)	NR			NR	NR

Abbreviations: NR, not reported; ORIF, open reduction internal fixation; ROM, range of motion; TAS, tibial anterior Surface; TLS, tibial lateral surface; TTA, tibiotalar tilt angle.
[a]Data are reported as average ± SD (range).

Appendix Table 3. Nonendpoint Secondary Procedures.

Author and Year	Other Secondary Procedures, n (% Total)		Average Time to Secondary Procedures
Bianchi et al[2] 2021	Debridement of bony impingement	7 (12.9)	
	Hardware removal	6 (11.1)	
	Medial malleolus osteotomy	6 (11.1)	
	Subtalar arthrodesis	5 (9.2)	
	Achilles tendon lengthening	2 (3.7)	
	Medial malleolus osteosynthesis	1 (1.8)	
	Midtarsal osteotomy	1 (1.8)	
Brunner et al[3] 2013	Polyethylene insert exchange	9	6.7 y (0.9-10.4)
	Medial displacement calcaneal osteotomy	2	3.2 y
	Z-shaped calcaneal osteotomy	1	10.1 y
	Supramalleolar osteotomy of the tibia	3	1.4 y
	Shortening osteotomy of the fibula	4	NR
	Medial ankle ligament reconstruction	1	2 y
	Peroneal tendon transfer	1	10.1 y
	Open arthrolysis and percutaneous lengthening of Achilles tendon	17	3.3 y (0.7-6.3)
	Open cyst debridement and filling with autologous cancellous bone	1	5.7 y
Clough et al[4] 2019	NR	NR	NR
Frigg et al[6] 2017	Subtalar arthrodesis	6	
	Talonavicular arthrodesis	2	
	Debridement of ankle joint	24	
	Lateral ligament repair	1	
	Posterior tibial tendon adhesiolysis	1	
	Dwyer osteotomy	2	
	Gastroc-lengthening	2	
	Polyethylene exchange	24	
Jastifer and Coughlin[14] 2015	Ankle debridement, poly exchange, and tendon repair	1	1 y 2 mo
	Ankle debridement and poly exchange	3	7 y 5 mo
	Triple arthrodesis	1	12 y 6 mo
	Ankle debridement, poly exchange, and gastrorecession	1	9 y 2 mo
Kraal et al[18] 2013	NR	NR	NR
Palanca et al[23] 2018	Removal of bone spurs and TAL	1	11.8 y
	Bone grafting to the tibia and talus and polyethylene exchange	1	10.8 y
	Subtalar fusion	1	13.7 y
	Polyethylene replacement and bone grafting of the tibia	2	10.4 y
	Calcaneal osteotomy	2	9.4 y
	Bone grafting of the tibia, routine polyethylene exchange	1	11.6 y
	Removal of the medial malleolus exostosis	1	12.7 y
	ORIF	1	44 d
	Bone grafting of the tibia and talus with routine polyethylene exchange and TAL	1	11.6 y
	Pending polyethylene replacement	1	15.6 y
Bedard et al[1] 2021	NR		

Abbreviations: ORIF, open reduction internal fixation; TAL, tendo-Achilles lengthening.
[a]Data are presented as n (range or %).